AD 282 121

UNCLASSIFIED

62-4-5

TECHNICAL RESEARCH NOTE 121

Tracking Performance in the Missile Master--Target Load, Tracking Time, and Rated Performance

USAPRO

U. S. ARMY
PERSONNEL
RESEARCH
OFFICE

Army Project Number
OJ 95-60-001

Electronics d-11

Technical Research Note 121

TRACKING PERFORMANCE IN THE MISSILE MASTER--TARGET LOAD, TRACKING TIME, AND RATED PROFICIENCY

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May 1962

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PREFACE

The present publication reports on a portion of Subtask d, "Identification of Effective Techniques and Procedures for Target Tracking and Radar Data Processing", of the ELECTRONICS Task, FY 62 Work Program of the U. S. Army Personnel Research Office. The entire research task is responsive to special requirements of the Army Air Defense Command, the Deputy Chief of Staff for Logistics (particularly the Chief Signal Officer), and the U. S. Continental Army Command, and furthers the U. S. Army Military Personnel Management (DCSPER) objective of developing and making available for operational use research products to optimize the selection, classification, assignment, and utilization of Army personnel.

New concepts of warfare have brought about the introduction into the Army of unique and complex electronic systems of far-reaching impact. Various staff and field organizations are charged with responsibility for maximizing the operational effectiveness of these systems. Since the effective operation and maintenance of these new electronic man-machine systems depend ultimately on human components, the need for human factors information is paramount.

The primary objective of the ELECTRONICS Task is to bring about the best utilization of electronics personnel in these systems. The objective can be accomplished through improved identification and assignment of individuals and crews to critical positions and through the development of optimum work methods and techniques for the operations that must be performed.

BRIEF

TRACKING PERFORMANCE IN THE MISSILE MASTER--TARGET LOAD, TRACKING TIME, AND RATED PROFICIENCY

Requirement:

Trackers in the Missile Master Fire Distribution system monitor and track aircraft picked up by radar. The present study was conducted to determine how tracking performance is affected by target load (number of targets assigned to be tracked), duration of tracking time, and proficiency of the tracker as rated by supervisors.

Procedure:

Eighteen qualified trackers--six rated high in tracking proficiency, six average, and six low--were required to track real targets on operational tracking consoles. Complete photographic records were made of tracking performance during six contiguous 10-minute periods. Load levels for the six periods varied from 3 to 18 targets. Accuracy indexes computed were: (1) percentage of instances tracker's "tags" were found to be on assigned targets; and (2) number of targets tracked with perfect accuracy in relation to number of targets assigned.

Findings:

1. As load level increased, average tracking accuracy decreased. The average <u>number</u> of targets tracked with perfect accuracy increased (although the percentage of targets tracked with perfect accuracy decreased). In fact, the average number of targets that can be tracked with perfect accuracy when all trackers are tracking is close to the target handling capability of the Missile Master.

2. No statistically significant differences in tracking performance were found among groups differing in rated proficiency.

3. No statistically significant differences in tracking performance were found across time periods. However, within 10-minute periods, a small but statistically significant decrement in mean accuracy score was found.

4. Individual trackers were found to differ appreciably in performance.

Recommendations:

1. Commanders should consider assigning individual trackers ten or more targets at a given time as a technique for increasing some aspects of tracker proficiency.

2. It is important that a technique be developed for identifying quickly those few assigned targets that are not being tracked with perfect accuracy. Such identification would eliminate the uncertainty associated with all targets when the location of one or more targets is not being correctly indicated by the tracker's tag.

3. Objective performance measures, rather than ratings, should be used in assigning individuals to specific tracking tasks. Such measures should be developed based on research data.

TRACKING PERFORMANCE IN THE MISSILE MASTER--TARGET LOAD, TRACKING TIME, AND RATED PROFICIENCY

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TRACKING PERFORMANCE IN THE MISSILE MASTER--TARGET LOAD, TRACKING TIME, AND RATED PROFICIENCY

BACKGROUND

The high performance characteristics of modern military aircraft and the destructive power of the weapons they employ require rapid and accurate transmission of air defense data. To meet this requirement, the Army has developed the Missile Master and other integrated fire distribution systems. These fire distribution systems detect, identify, and track aircraft. At the same time, these systems effect the interchange of information concerning the air situation and fire unit status among higher headquarters, adjacent fire distribution systems, and air defense fire units. In short, they coordinate the fire of a number of batteries at a number of enemy aircraft.

The U. S. Army Personnel Research Office is engaged in a program of research to improve the selection and utilization of personnel in air defense fire distribution systems. The research program encompasses the study of such critical operator functions as the detection and monitoring of airborne targets on radarscopes, target tracking and radar data processing, assignment of weapons against airborne targets, and communications and control. The ultimate objectives of the planned experimentation are (1) the improved assignment of individuals and crews to critical positions, (2) the more effective allocation of functions to personnel, and (3) heightened efficiency of work methods.

PURPOSE

The present exploratory study concerned performance of the tracker in the Missile Master system. Trackers monitor and track aircraft picked up by the acquisition radar, providing early input into the fire distribution system. In a typical situation, radar blips appearing on a Surveillance and Entry (S and E) Console are selected for tracking. The S and E operator positions circular markers, or tags, over the blips, thereby establishing "tracks." These tracks are then transferred electronically to Tracking Consoles. Trackers are charged with keeping the tags over the blips.

In a manual rate-aided tracking system such as was used in the present study, the tracker maintains the tags over the blips by use of a tracking stick. Successive manual positionings of a tag generate a "rate" and direction of movement. The positions of the tags determine the geographic reference data entered into the system. The accuracy with which the tags are positioned affects the process of designating the fire units to engage the targets and the speed with which the fire units are able to lock on to the targets. The more precise the tracking, the less ambiguous the air picture is to fire unit operators, who may have a number of blips on their scopes in addition to the specific tracks designated for engagement. Confusion is minimized and engagement facilitated when tags are centered directly over the blips with which they are associated.

An individual tracker may be assigned from one to several targets to track at one time, the specific number being determined by the number of trackers available, the number of potential targets in the air, and the capacity of the system.

The specific purpose of the present study was to assess the performance of trackers of high, average, and low rated proficiency under varying conditions of load level (number of targets to be tracked at one time), and continuous time spent in tracking.

METHOD

Experimental Design

Experimental conditions provided controlled variation among the three variables: load level, length of tracking period, and proficiency of trackers as rated by superiors.

Tracking performance during six contiguous 10-minute periods was recorded photographically. Load levels of 3, 6, 9, 12, 15, and 18 targets were presented. Load level by time period combinations were arranged in a 6 by 6 Latin square design. The design was repeated twice to accommodate 18 trackers--six rated highly proficient, six of average proficiency, and six of low proficiency. The order in which the six load levels were presented to each tracker across the six 10-minute periods is shown in Table 1. This design permitted separate analysis of the independent and correlated measures obtained in the study (Edwards, 1950).

Selection of Trackers

During the study, the Missile Master was operated on a three-shift basis with a different crew assigned to each shift. A roster of all trackers within each shift was reviewed by the duty officer and senior NCOs, who deleted the names of those men whose low proficiency could be attributed largely to lack of experience. The remaining names were rank-ordered and the men categorized as high, average, and low proficiency trackers. As far as possible, trackers were chosen from the top of the high group, the bottom of the low group, and the middle of the average group, to achieve maximum differentiation between groups. With six ratings available for each tracker in one of the shifts, a measure of inter-rater agreement could be computed. Using Ebel's method (Guilford, 1954), the reliability coefficient obtained for the six raters was .81.

Stimulus Presentation

In addition to the Tracking Console shown in Figure 1, equipment included a Surveillance and Entry Console upon which the tracker is normally dependent for input and direction. A complete description of the equipment used in the present experiment is contained in FM 44-10, U. S. Army Air Defense Fire Distribution System AN/FSG-1 Missile Master (unclassified title).

Table 1

SCHEDULE OF EXPERIMENTAL CONDITIONS FOR EACH TRACKER

Rated Proficiency Level	Tracker Number	Consecutive 10-minute Period 1	2	3	4	5	6
	1	18[a]	15	9	12	3	6
	8	15	12	6	18	9	3
	15	9	6	15	3	18	12
High	4	12	18	3	15	6	9
	11	3	9	18	6	12	15
	18	6	3	12	9	15	18
	7	18	15	9	12	3	6
	14	15	12	6	18	9	3
	3	9	6	15	3	18	12
Average	10	12	18	3	15	6	9
	17	3	9	18	6	12	15
	6	6	3	12	9	15	18
	13	18	15	9	12	3	6
	2	15	12	6	18	9	3
	9	9	6	15	3	18	12
Low	16	12	18	3	15	6	9
	5	3	9	18	6	12	15
	12	6	3	12	9	15	18
High[b]	19	12	18	3	15	6	9

[a]Cell entries represent number of targets presented.

[b]The nineteenth subject was intended as a replacement for man No. 4 whose film record was feared damaged. However, no data were lost. The scores for these two men, both from the same crew, were nearly identical across all conditions. For the sake of simplicity, 18 cases were used in the main analysis of variance. All nineteen cases were used in all other analyses.

Figure 1. A Tracking Console

The tracker has his hand positioned on the tracking stick which enables him to control the tracking symbols appearing on the scope of his console.

Targets used in this experiment were selected by the experimenters from operational radar input reflective of the air environment at the specific times testing sessions were conducted. Targets were so presented as to minimize bias due to time of day, weather, location, density, course and speed of targets, and target life. Each blip selected was judged by the experimenter and a qualified S and E operator to be of good quality, and at a sufficient distance from any other blip to avoid confusing the tracker.

As soon as a target was selected, the S and E operator placed a stationary tracking tag directly over the target and immediately transferred the track to the tracker. To minimize effect of differences between S and E operators on trackers' performance, rates were not established by S and E operators for any of the targets. Tracks were assigned at the approximate rate of one every 10 seconds so that all tracks for a given period were assigned--and most rates established--within the first four minutes. Figure 2 shows a radarscope presentation with five established tracks.

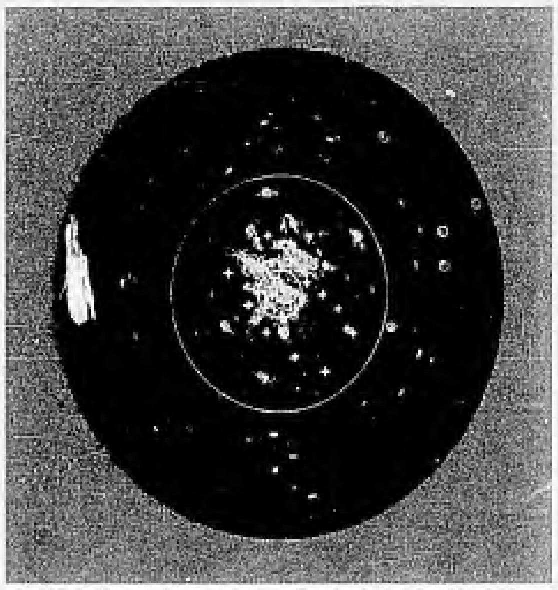

Figure 2. A Radarscope Presentation as Seen by a Tracker

Occasionally radar blips fade and may not be visible for several sweeps of the radar; or the target which the blip represents may land and the blip disappear. Whenever a fade was reported by a tracker during the study, the tag was withdrawn from the scope. If this occurred in the first seven minutes of any period, a new target was assigned in order to maintain proper load level at the start of the final three minutes designated as the critical measurement period. If a fade was reported in the last three minutes of the period, the target was withdrawn and no replacement was made, in order not to interfere with tracker performance. All tags were removed at the end of each 10-minute period. After an interval of 20 to 25 seconds, assignment of target tracks for the next period was initiated.

The specific instructions given the trackers in the experiment are shown in the Appendix. The experimental setting closely approximated operational conditions, with the following exceptions necessitated by the experimented design:

1. While the rate and direction of movement of the tag is often established before control is passed to the tracker, this practice was not followed during the present study. Trackers themselves had to establish rates for all tags.

2. All tags were taken away from the trackers at the end of each 10-minute period, and new tracks were assigned. Delay between periods averaged 20 to 25 seconds.

3. The number of tracks per tracker varied over a wider range than is the usual practice.

Recording the Data

A display identical to that appearing on the scope of the tracker was presented on another console. The second scope was photographed continuously during each testing session with a 35-mm Flight Research Camera, synchronized to expose one frame of film for each 360-degree revolution of the radar sweep. Thus data collection did not interfere in any way with the tracker and his operations.

Scoring

The last three minutes of each period were considered the critical measurement period. This procedure allowed time for tracking performance to stabilize. However, performance was recorded throughout each hour-long session. The film record for each tracker was scored frame by frame from beginning to end of each load level by time period combination. For each frame, the tracker received a credit of 1 for each assigned target with which the tracking symbol was in contact. A man's accuracy score was the ratio of the total number of times he was on target (sum of credits) to the maximum number of times he could have been on target had he tracked perfectly.

When a tag was withdrawn because of a reported fade or a target's moving off the scope, the scorer determined whether, in fact, the target had disappeared or whether it was still present and trackable. If the target had disappeared, that target was ignored in the remaining frames in that period. If the target was found to be trackable, the remaining frames were scored as zero for that target.

Scores were calculated for the critical three-minute measurement period. The arc sine transformation was applied to the scores to correct for the marked skewness associated with the lower load levels (Table 2) in order to meet the assumptions necessary for an analysis of variance.

RESULTS

The analysis of variance is summarized in Table 3. The only variable for which significant differences in performance were found was load level. No significant differences were found among proficiency groups or ten-minute tracking periods.

Performance Differences Associated with Load Level

Considering the trend of accuracy scores across the various load levels (Figure 3), accuracy appears to be linearly related to the number of targets the tracker was assigned in the present study. The regression coefficient or slope of accuracy on load level was -.014. Thus, for each added target, accuracy dropped .014 on the accuracy scale. The slope of the linear trend, as tested by use of the arc sine transformed data, was found to be significant at the .05 level ($t = 28.61$).

Table 2

FREQUENCY DISTRIBUTION OF TRACKING ACCURACY SCORES BY LOAD LEVEL

Accuracy Score	Number of Targets 3	6	9	12	15	18
.98 - 1.00	18	12	8	8	2	1
.95 - .97		3	3	1	3	2
.92 - .94		1		1	2	2
.89 - .91			2		1	2
.86 - .88			2	2	3	1
.83 - .85		2	1			2
.80 - .82			1	1	1	2
.77 - .79				2		
.74 - .76	1			1	1	2
.71 - .73					1	
.68 - .70			1		1	1
.65 - .67			1	1	1	
Less than .65		1		2	3	4

Table 3

ANALYSIS OF VARIANCE OF EXPERIMENTAL VARIABLES

Source of Variation	Sums of Squares	df	Mean Square	F
Proficiency groups	.09	2	.05	.08
Residual between subjects	9.01	15	.60	
Total between subjects	9.10	17		
Load level	9.86	5	1.97	14.07*
Ten-minute periods	.55	5	.11	.79
Residuals	11.46	80	.14	
Total within subjects	21.87	90		
Total	30.97	107		

*Significant at the .05 level.

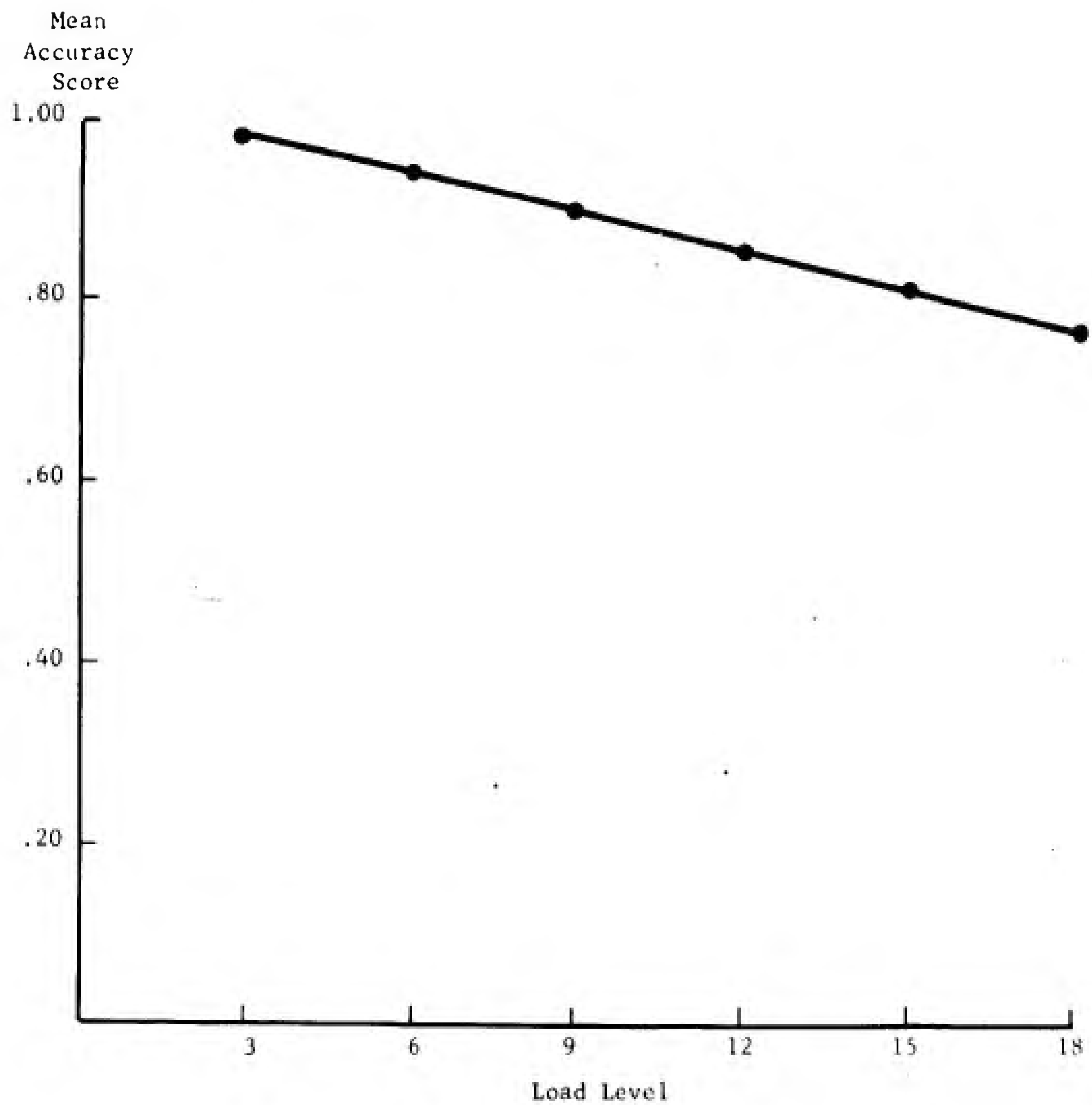

Figure 3. Mean Accuracy Scores of All Trackers at Each Load Level

Although mean accuracy decreased as load level increased, the mean number of targets tracked with perfect accuracy increased (Figure 4). Assuming that something less than perfect accuracy is required for effective system operation, the values in Figure 4 may be regarded as the lower limits of usable target data that may be provided. Additional target data based on targets that are not tracked precisely through all time periods may still be usable.

Differences Associated with Duration of Tracking Time

Mean accuracy scores of all trackers for each 10-minute period of the hour-long tracking task are given below. Fluctuations were small, directionally unpredictable from period to period, and, judging from the nonsignificant F of .79 for the time variable shown in Table 3, attributable to chance variation.

MEAN ACCURACY SCORES OF 19 TRACKERS
FOR SIX TEN-MINUTE TIME PERIODS

	Ten-Minute Time Periods					
	1	2	3	4	5	6
Last three minutes	.87	.88	.91	.85	.91	.88

Further analysis of accuracy within 10-minute periods revealed a small but significant decrement in mean performance from minutes 5 through 7 to minutes 8 through 10. Mean raw accuracy scores were .88 and .85, respectively, for the two intervals. The t test for correlated data applied to the transformed mean accuracy scores yielded a value of 4.33, significant at the .05 level. Figure 5 depicts the mean accuracy scores of all trackers by load level for minutes five through seven and for the last three minutes of tracking. Figure 6 shows the corresponding data by tracking period. Direction of differences in performance within 10-minute period is consistent across all load levels and all time periods.

Individual Differences in Tracker Performance

While no statistically significant differences were found associated with proficiency group, individuals were found to differ appreciably in their target tracking performance. Range in mean accuracy scores was .58 to .98 (Table 4). The reliability of the individual differences was checked by computing Ebel's intra-class correlation across load levels. The reliability coefficient for the six load levels combined was .76, indicating that the variations in performance were not due to error of measurement alone.

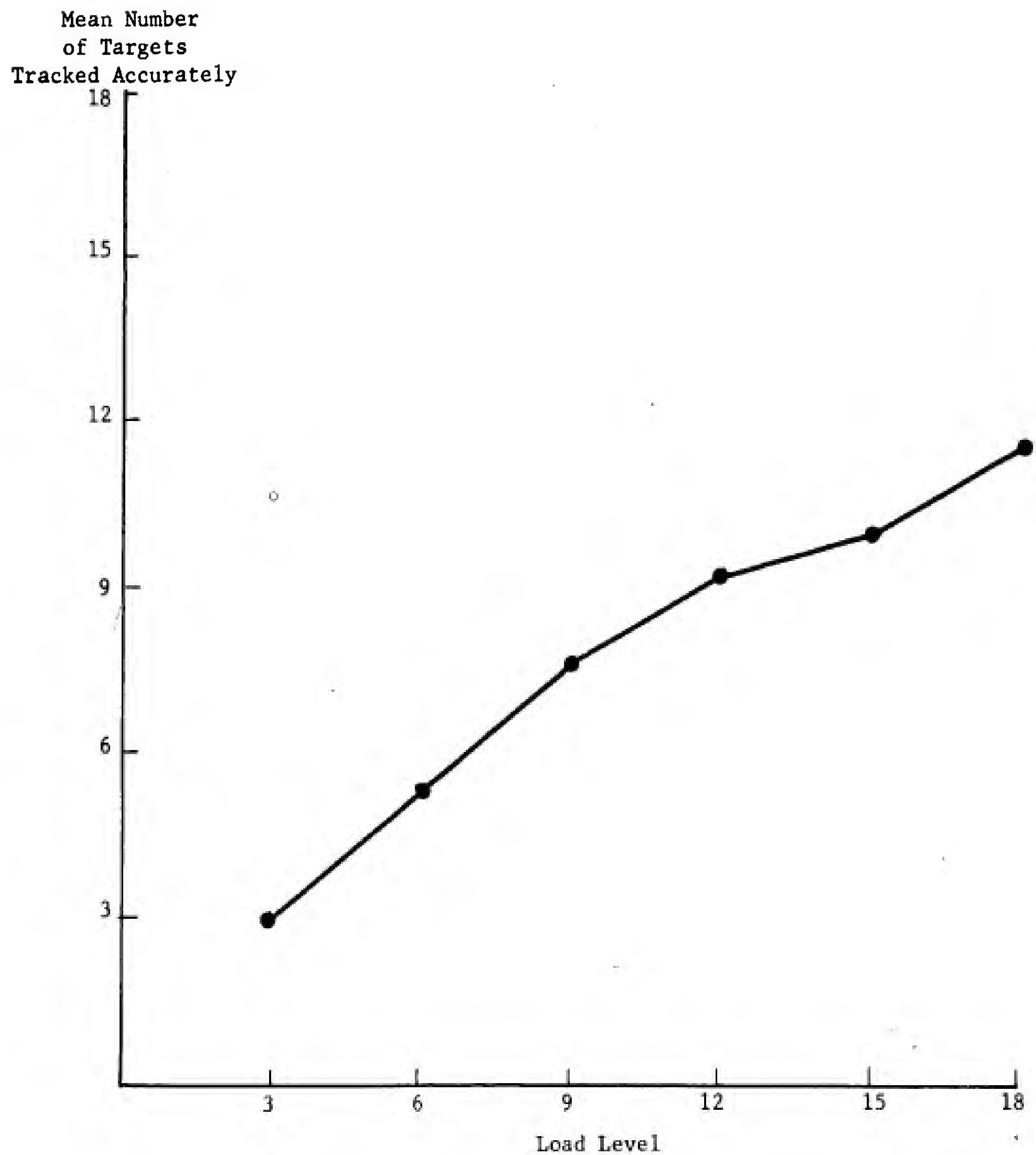

Figure 4. Mean Number of Targets Tracked with 100% Accuracy at Each Load Level

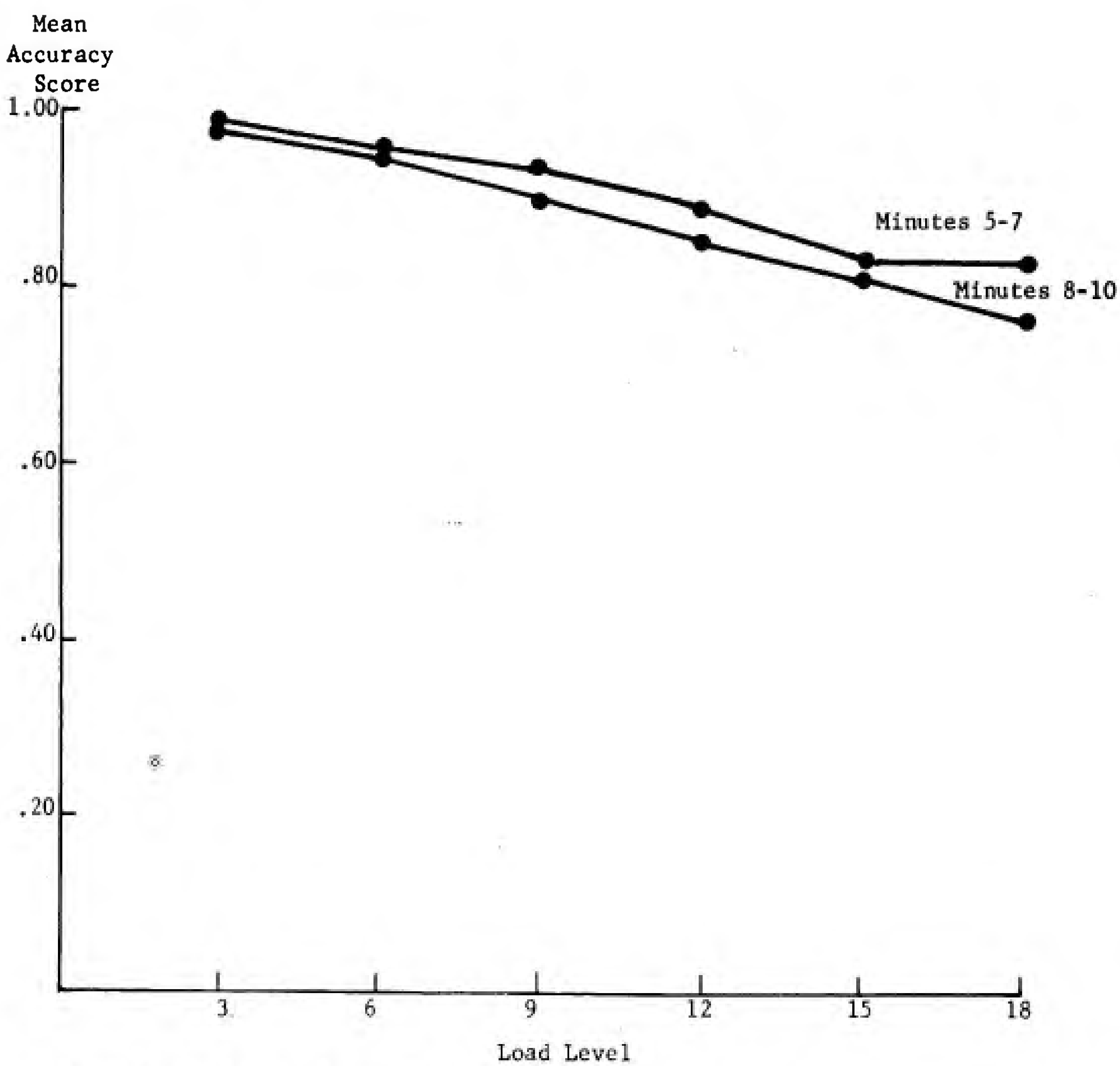

Figure 5. Mean Accuracy Score at Each Load Level for Two Time Intervals

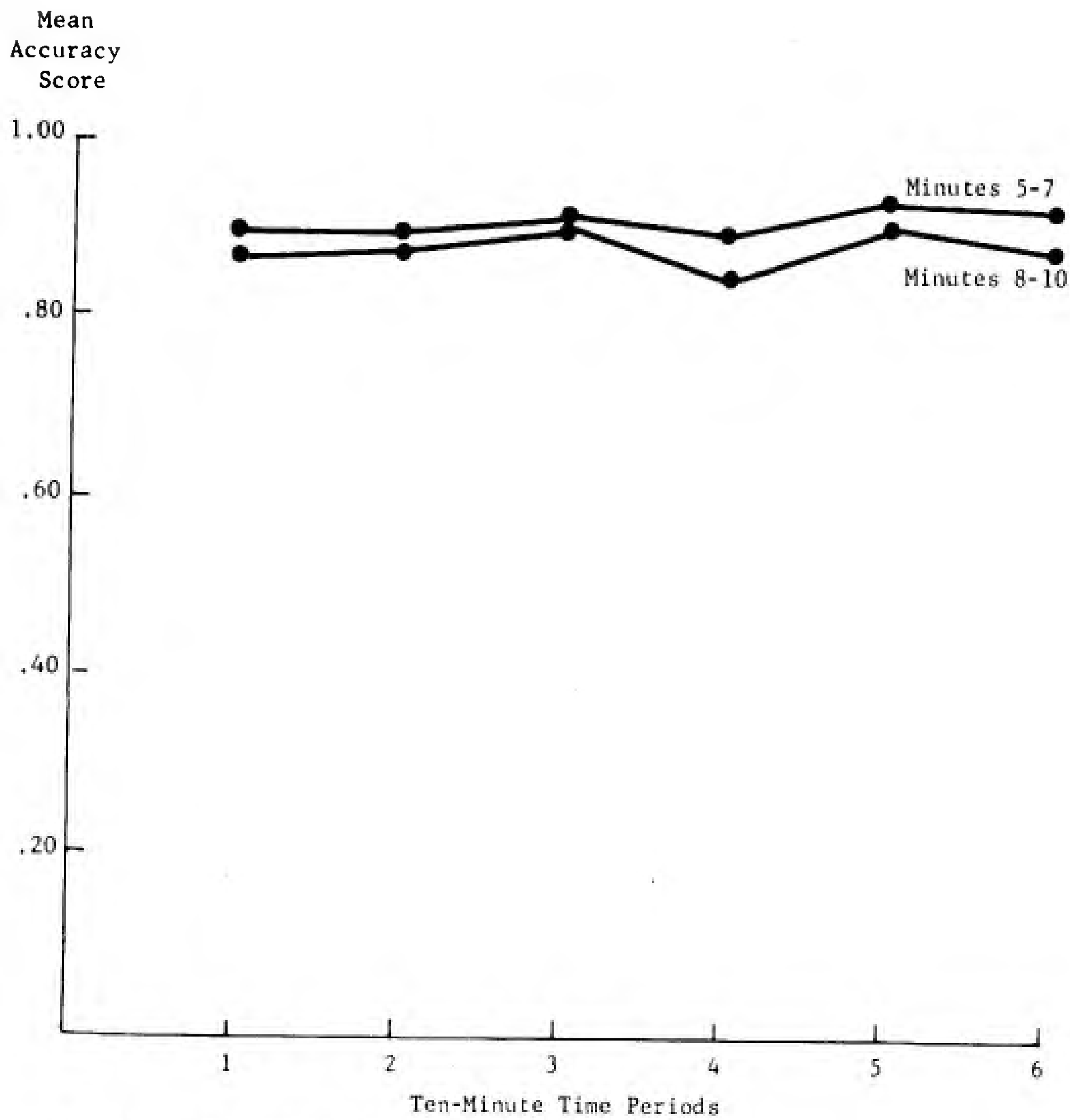

Figure 6. Mean Accuracy Score for Two Time Intervals, by Time Period

Table 4

RAW ACCURACY SCORES FOR SIX LOAD LEVELS SHOWING INDIVIDUAL, PROFICIENCY GROUP, AND LOAD LEVEL MEANS

Rated Proficiency Group	Man	Load Level 3	6	9	12	15	18	Individual Means	Group Means
High	1	1.00	1.00	1.00	.99	.73	.74	.91	.91
	4	1.00	1.00	1.00	1.00	.98	.80	.96	
	8	1.00	1.00	.88	.76	.87	.45	.83	
	11	1.00	.99	.98	.86	.82	.74	.90	
	15	1.00	.83	1.00	.78	.86	.83	.88	
	18	1.00	.94	.68	.87	.87	.89	.88	
	19	1.00	1.00	1.00	.94	.97	.91	.97	
	$\bar{X}$	1.00	.97	.93	.89	.87	.77		
Average	3	1.00	.99	1.00	1.00	.95	.92	.98	.87
	6	1.00	1.00	.87	.82	.92	.69	.88	
	7	1.00	.97	.97	.97	.56	.64	.85	
	10	1.00	1.00	.99	1.00	.54	.95	.91	
	14	.74	1.00	.82	.67	.55	.81	.73	
	17	1.00	.97	.97	.78	.76	.52	.83	
	$\bar{X}$	.96	.99	.94	.87	.71	.76		
Low	2	1.00	.99	.95	1.00	1.00	.86	.97	.88
	5	1.00	.83	.83	.51	.66	1.00	.81	
	9	1.00	1.00	.91	.99	.90	.95	.96	
	12	1.00	.96	.91	1.00	.94	.94	.96	
	13	1.00	.55	.67	.46	.70	.12	.58	
	16	1.00	1.00	1.00	1.00	.96	.84	.97	
	$\bar{X}$	1.00	.89	.8[illegible]	.83	.86	.79		

IMPLICATIONS OF FINDINGS

Load Level

In general, trackers perform better than is commonly believed. If it is necessary to know before tracking begins that each and every target will be tracked with perfect accuracy for as long as it appears on the scope, no more than three targets should be assigned to the average tracker. If a mean accuracy of 95 percent (tags on targets 95 percent of the time) is acceptable, the average tracker can be assigned up to six targets. The average number of targets tracked with perfect accuracy is then 5.4. If mean accuracy of 93 percent is acceptable, the average tracker can be assigned up to eight targets. In that event, he can be expected to track seven targets with perfect accuracy. However, if tracking is less than 100 percent accurate, it will be difficult--and sometimes impossible--for tactical monitors or firing units to know which of the assigned targets tags are on or off at any particular moment in time. Judging from performance in the present study, when all trackers are tracking they can track with perfect accuracy a number of targets which is close to the target handling capability of the system.

Figure 3 and Figure 4 describe tracker performance in terms of two measures of accuracy. The number of targets tracked with perfect accuracy (Figure 4) has, in and of itself, a significant implication. The air defense commander is concerned with the reduction in accuracy likely to result when the assigned target load is large. However, under certain circumstances--saturation, for example--the primary concern may be with the total number of targets that can be tracked with perfect accuracy regardless of the number of errors made in tracking other targets. From this point of view, it is significant that the number of targets tracked with perfect accuracy was found to increase with each increase in load level investigated in the present study.

It is also significant that the number of targets tracked with perfect accuracy is appreciably higher than would be expected if tracking errors were assumed to be distributed randomly over targets. To state this finding differently, it is clear that errors tend to be grouped. Presumably, if a tracker is in error in tracking a particular target during one sweep of the radar, there is heightened probability that he will be in error on the next sweep. Once a good rate has been established for a track, the tracking symbol tends to stay on target without major--or frequent--correction by the tracker, provided the target does not change direction or speed.

While the relatively few targets not being tracked with perfect accuracy cannot be identified until tracking is under way, the possibility exists that means of spotting them quickly can be developed. Such identification would eliminate uncertainty associated with all targets when the location of one or more targets is not being correctly indicated by the tracker's tag.

Duration of Tracking Time

Deterioration of performance within 10-minute periods, but not across periods, may be due to the fact that trackers had an opportunity to stretch, light a cigarette, or stand up during the 20- to 25-second time lapse between tracking periods. These short breaks may have been of sufficient duration to allow the men to recover from the cumulative effects of fatigue. Possibly the difference in treatment of fades--new targets were assigned in place of fades occurring during the first seven minutes but not for those occurring during the last three minutes--contributed to the higher accuracy scores obtained in minutes 5 through 7. However, recovery effects similar to those obtained in the present study have been reported in studies of vigilance, elements of which are present in the tracking task. Diverting attention from the tracking task for several seconds at frequent intervals may help to sustain the quality of tracking performance, and may even result in greater overall accuracy.

Individual Differences in Tracking

Analysis of variance results indicate that tracking accuracy as measured in the present study was not reflected in supervisors' evaluations of individual tracker proficiency. With no readily usable measures of tracking accuracy available, supervisors have made a practice of evaluating performance by observing the scopes while tracking was in progress. Evidence that such observation does not insure accurate performance appraisals rests in the film record of the present study, which revealed serious tracking errors that were not immediately detected by the S and E operators or by the experimenters who monitored tracker performance.

The appreciable individual differences observed in the present study suggest that tracking output may be increased through application of improved techniques for measuring tracker potentiality and performance, and by optimum work methods, if in fact individual performance differences are attributable to different work methods of good and poor trackers. Realistic and objective performance measures would permit commanders and supervisory personnel to capitalize on individual differences. More specifically, unacceptable trackers could be identified and reassigned; teams could be constituted on the basis of differing contributions to joint product. Such performance measures are also essential to productive research directed toward optimum work methods.

CONCLUSIONS

When all trackers are tracking and have been assigned targets to the capacity of the system, they can be expected to track about 90% of these with perfect accuracy.

Frequent short breaks in the tracking task may help to sustain quality of tracking performance, and may even improve it.

Differences in work methods may be associated with observed differences in tracker performance.

The appreciable individual differences observed in the study indicate that the development of improved screening techniques may further increase tracking output.

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APPENDIX

DETAILED INSTRUCTIONS FOR EXPERIMENTAL PROCEDURES

Call in the subjects and brief them informally regarding USAPRO research at Missile Master. Mention the following points:

1. We are studying important positions in the Missile Master system.

2. S and E and Tactical Monitor positions will also be studied.

3. We are looking for ways to make the tracking position more interesting, more challenging, and more effective.

4. Their cooperation in this study will help improve jobs like these.

At this point, give the subjects the following instructions:

> "There will be some slight differences between your normal duties and what we are asking you to do today. These differences are important, so please listen carefully."
>
> "First, all tracks that are given to you will be without rates. You are to start tracking as soon as possible, get rates in, and keep all tracks up-dated."
>
> "Second, once a particular group of targets has been assigned to you, you will track them only for a short period of time. The targets will then be dumped and you will be given a new set of targets to track."
>
> "Third, rather than your having only a few targets to track all the time, sometimes you will have to track large numbers of targets."
>
> "If you should have a video fade while tracking, you will sequence with the "fade" button as you normally do. If at any time your yellow fade-light is lit and there is still no video under or near your symbol, you will report this by saying "Video fade" and giving the channel number as you usually do. The S and E will tell you what to do."
>
> "If a target and symbol leave the scope, you will report this by saying "Target out of range" and giving the channel number. The S and E will tell you what to do." (S and E replaces fades for first 7 minutes.)
>
> "Are there any questions at this point?"

Answer all questions and re-read appropriate portions of the instructions if necessary. When you are satisfied that the subject understands exactly what to do, have him sit at the designated console. Say:

> "Before we begin, adjust your scope to suit yourself. Make sure, however, that you keep your local dots turned down completely1/. Check out your console and be sure it is working properly."

NOTE: Check the subject's scope to insure that local dots are turned down.

1/Local dots are spots which appear on each scope showing the position of all active tags other than those that are assigned to that particular console. The intensity of these can be turned down so that they are not visible.

AD Div 23/1, 28/4

UNCLASSIFIED
Human Resources Research
--Personnel Utilization

U. S. Army Personnel Research Office, OCRD, DA
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(DA Project OJ 95-60-001) Unclassified Report

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